May 12, 1859.

Sir BENJAMIN C. BRODIE, Bart., President, in the Chair.

The following communications were read:—

I. "On the Resistance of Glass Globes and Cylinders to collapse from external pressure, and on the Tensile and Compressive Strength of various kinds of Glass." By WILLIAM FAIRBAIRN, Esq., C.E., F.R.S., and T. TATE, Esq., F.R.A.S. Received May 3, 1859.

(Abstract.)

The researches contained in this paper are in continuation of those upon the Resistance of Wrought-Iron Tubes to collapse, which have been published in the 'Philosophical Transactions' for 1858. The results arrived at in those experiments were so important as to suggest further inquiry under the same conditions of rupture with other materials; and glass was selected, not only as differing widely in its physical properties from wrought iron, and hence well fitted to extend our knowledge of the laws of collapse, but because our acquaintance with its strength in the various forms in which it is employed in the arts and in scientific research is very limited. To arrive at satisfactory conclusions, the experiments on this material were extended so as to embrace the direct tenacity, the resistance to compression, and the resistance to bursting, as well as the resistance to collapse.

The glass experimented upon was of three kinds:—

	Specific gravity.
Best flint-glass	3·0782
Common green glass....	2·5284
Extra white crown-glass	2·4504

Tenacity of Glass.—For reasons detailed by the authors, the experiments upon the direct tenacity of glass made by tearing specimens asunder are less satisfactory than those in the rest of the paper; and it is argued that more reliance is to be placed upon the tenacity deduced from the experiments on the resistance of globes to bursting in which water-pressure was employed, than upon the tenacity obtained directly by tearing specimens asunder. The

results obtained by the latter method give the following mean results:—

	Tenacity per square inch in pounds.
Flint-glass	2413
Green glass	2896
Crown-glass	2346

Resistance of Glass to Crushing.—The experiments in this section were made upon small cylinders and cubes of glass crushed between parallel steel surfaces by means of a lever. The cylinders were cut of the required length from rods drawn to the required diameter, when molten, and then annealed, in this way retaining the exterior and first cooled skin of glass. The cubes were cut from much larger portions, and were in consequence probably in a less perfect condition as regards annealing. Hence, as might have been anticipated, the results upon the two classes of specimens, although consistent in each case, differ widely from one another.

The mean compressive resistance of the cylinders, varying in height from 1 to 2 inches, and about 0·75 inch in diameter, is given in the following Table:—

Description of glass.	Height of cylinder in inches.	Mean crushing weight per sq. in.		Mean crushing weight per sq. in.	
		in pounds.	in tons.	in pounds.	in tons.
Flint-glass	1	29,168	13·021	27,582	12·313
	1·5	20,775	9·274		
	2·0	32,803	14·644		
Green glass ...	1	22,583	10·081	31,876	14·227
	1·5	35,029	15·628		
	2·0	38,105	16·971		
Crown-glass ...	1·0	23,181	10·348	31,003	13·840
	1·5	38,825	17·332		

The specimens were crushed almost to powder by the violence of the concussion; it appeared, however, that the fracture occurred in vertical planes, splitting up the specimen in all directions. Cracks were noticed to form some time before the specimen finally gave way; then these rapidly increased in number, splitting the glass into innumerable prisms, which finally bent or broke, and the specimen was destroyed.

The following Table gives the results of the experiments upon the cut cubes of glass :—

	Mean resistance to crushing	
	in pounds.	in tons.
Flint-glass	13,130	6·861
Green glass	20,206	9·010
Crown-glass	21,867	9·762

Hence, comparing the results on cylinders with those on cubes, we find a mean superiority in the former case in the ratio of 1·6 : 1, due to the more perfect annealing of the glass.

On the Resistance of Glass Globes to internal pressure.—In these experiments the tenacity of glass is obtained by a method free from the objections to that before detailed. Glass globes, easily obtained of the requisite sizes, in a nearly spherical form, were subjected to an internal pressure obtained by means of a hydraulic pump, uniformly and steadily increased till the globe gave way. The lines of fracture radiated in every direction from the weakest part, passing round the globe as meridians of longitude and splitting it up into thin bands, varying from $\frac{1}{20}$th to $\frac{1}{8}$th of an inch in breadth.

The following Table gives the results of the experiments on the resistance of glass globes to internal pressure :—

Description of glass.	Diameters.	Thickness.	Bursting pressure per square inch.
	Inches.	Inches.	Pounds.
Flint-glass	4·0 ×3·98	0·024	84
	4·0 ×3·98	0·025	93
	4·0	0·038	150
	4·5 ×4·55	0·056	280
	5·1 ×5·12	0·058	184
	6·0	0·059	152
Green glass......	4·95×5·0	0·022	90
	4·95×5·0	0·020	85
	4·0 ×4·05	0·018	84
	4·0 ×4·03	0·016	82
Crown-glass ...	4·2 ×4·35	0·025	120
	4·05×4·2	0·021	126
	5·9 ×5·8	0·016	69
	6·0 ×6·3	0·020	86

The formula which expresses the relation of the bursting pressure to the thickness and diameter of the globe, is—

$$P = \frac{aT}{A};$$

where a = the longitudinal sectional area of the material in square inches, that is in the line of rupture or line of minimum strength; A = the longitudinal sectional area of the globe in square inches; and T = the tenacity of the glass in pounds per square inch. Hence from the above experiments we deduce—

$$\begin{aligned} &\quad\text{Pounds.}\\ T &= 4200 \text{ for flint-glass,}\\ &= 4800 \text{ for green glass,}\\ &= \underline{6000} \text{ for crown-glass.}\\ &\quad 5000 = \text{mean tenacity of glass.} \end{aligned}$$

Here the mean tenacity is nearly twice that obtained in the experiments upon thick bars; a result, which perhaps corresponds with the difference between the crushing strength of cylinders and cubes, and is largely attributable to the condition of annealing.

On the Resistance of Glass Globes and Cylinders to an external pressure.—The manner of conducting these experiments did not differ in any essential detail from that pursued in the experiments upon wrought iron. The globes and cylinders, after having been hermetically sealed in the blowpipe flame, were fixed in a wrought-iron boiler communicating with a hydraulic pump. In this position an increasing pressure was applied until the globes broke, the amount of pressure at the time being noted by means of a Schäffer pressure-gauge. During the collapse the globes were reduced to the smallest fragments, so that no indication of the direction of the primary lines of fracture could be discovered.

The following Table contains a summary of the results on glass globes subjected to an external pressure:—

Description of glass.	Diameters.	Thickness.	Collapsing pressure per square inch.
	Inches.	Inches.	Pounds.
Flint-glass	5·05×4·76	0·014	292
	5·08×4·7	0·018	410
	4·95×4·72	0·022	470
	5·6	0·020	475
	8·22×7·45	0·010	35
	8·2 ×7·2	0·012	42
	8·2 ×7·4	0·015	60
	4·0 ×3·98	0·024	(900*)
	4·0	0·025	(900*)
	6·0	0·059	(1000*)
Green glass	5·0×5·02	0·0125	212

The following Table contains a similar summary of the results upon cylindrical vessels :—

Description of glass.	Diameters.	Length.	Thickness.	Collapsing pressure per square inch.
	Inches.	Inches.	Inches.	Pounds.
Flint-glass ...	3·09	14·0	0·024	85
	3·08	14·0	0·032	103
	3·25	14·0	0·042	175
	4·05	7·0	0·034	202
	4·05	7·0	0·046	380
	4·06	13·8	0·043	180
	4·02	13·8	0·064	297
	3·98	14·0	0·076	382
	4·05	7·0	0·079	(500†)

The paper includes an investigation of the laws of collapse as exhibited in these results, and the following general formulæ are obtained :—

For glass globes. . . . . $P=28{,}300{,}000\times\dfrac{k^{1\cdot4}}{D^{3\cdot4}}$,

For glass cylinders . . . . $P=740{,}000\times\dfrac{k^{1\cdot4}}{D.L}$,

where $P=$ the collapsing pressure in pounds per square inch ; $k=$ thickness in inches; D and $L=$ diameter and length respectively in inches.

* These globes remained unbroken.
† Remained unbroken.

These are the general formulæ for glass vessels subjected to an external pressure, and the latter is precisely similar to that found for sheet-iron cylinders.

Transverse Strength of Glass.—The authors derive the general formula

$$W=3140\times\frac{K.D}{l},$$

where W = breaking weight in pounds, K = area of transverse section, D = depth of section, l = length between supports;—to express the transverse strength of a rectangular bar of glass supported at the ends and loaded at the middle.

II. "On the Atomic Weight of Graphite." By Benjamin C. Brodie, Esq., F.R.S., Pres. C.S., Professor of Chemistry in the University of Oxford. Received May 5, 1859.

(Abstract.)

In this paper the author arrives at the following results:—That carbon in the form of graphite forms a system of peculiar compounds, different from any compounds of carbon yet known, and capable of being procured only from graphite. That graphite, within certain limits, functions as a distinct element, capable indeed of being converted by certain processes of oxidation into carbonic acid and thus identified with the other forms of carbon, but having a distinct atomic weight, namely 33 (H=1).

After the detail of certain experiments by which the author was led to believe in the existence of a distinct system of compounds of graphite, an account is given of a peculiar crystalline substance formed by the prolonged oxidation of graphite. This substance consists of transparent plates of a pale yellow colour, which exhibit under the microscope an appearance distinctly crystalline. The analysis of this substance gave for its formula $C_{11}\,H_4\,O_5$ (C=12, O=16). From the ratio of the hydrogen to the oxygen in this substance, from the circumstance that it is procured from graphite alone, and from its general physical properties, it is inferred that this substance is the term in the system of graphite which corresponds to the compound of silicon, oxygen and hydrogen, in the system of silicon, procured by Wöhler from the graphitoidal form of that element,